Efficient Rendering of Massive and Repetitive patterns

Presented by Sehyun Joo, KAIST

Review

- Noise filtering in Monte Carlo rendering
  - Random Parameter Filtering (RPF) uses statistical dependency between sample values and random parameters to filter MC noise.

  - Non-Local Means Filtering (NLM) reduces noise by weighting all pixels in the image based on the variance.

Papers

- Modular Flux Transfer : Efficient Rendering of High-Resolution Volumes with Repeated Structures
  (Zhao et al., SIGGRAPH 2013)

- Multi-Scale Modeling and Rendering of Granular Materials
  (Meng et al., SIGGRAPH 2015)

Modular Flux Transfer

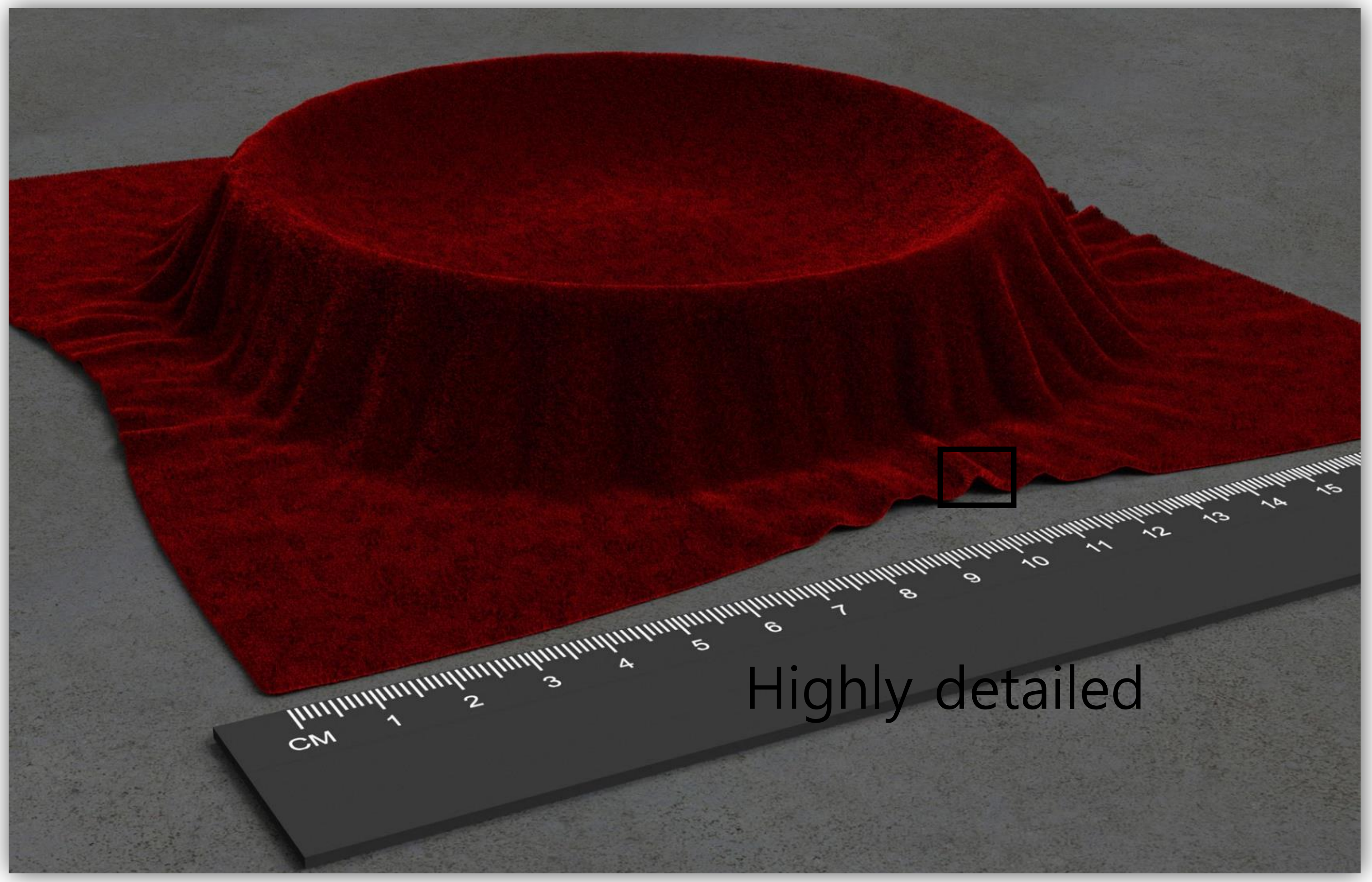
Efficient Rendering of High-Resolution Volumes with Repeated Structures (SIGGRAPH 2013)

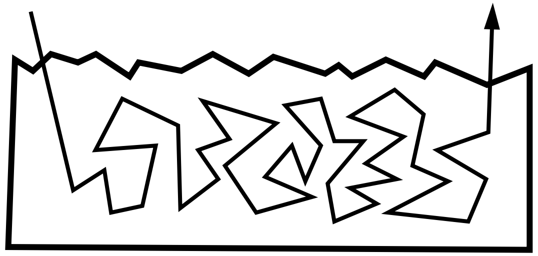
Shuang Zhao Miloš Hašan Ravi Ramamoorthi Kavita Bala

Slides based on Zhao's slide
(https://shuangz.com/publications.htm)

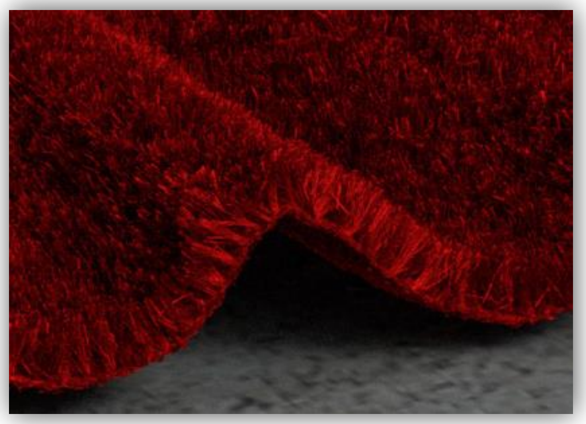
Challenge

Velvet





Highly scattering

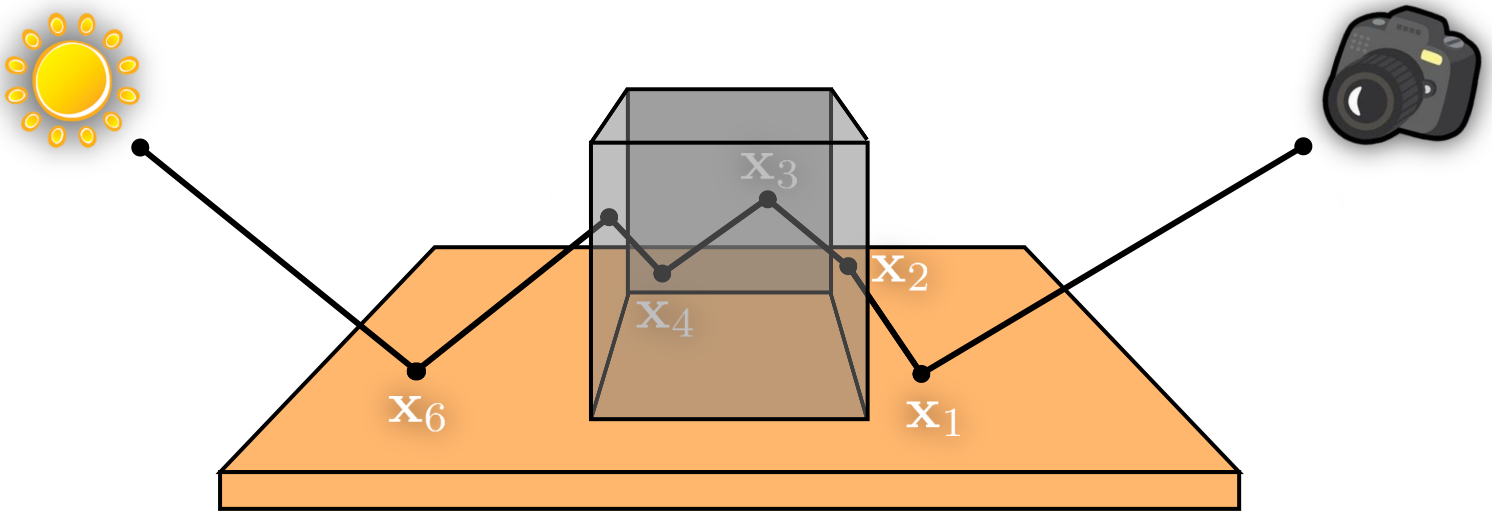


Tons of voxels

Background

Path Formulation

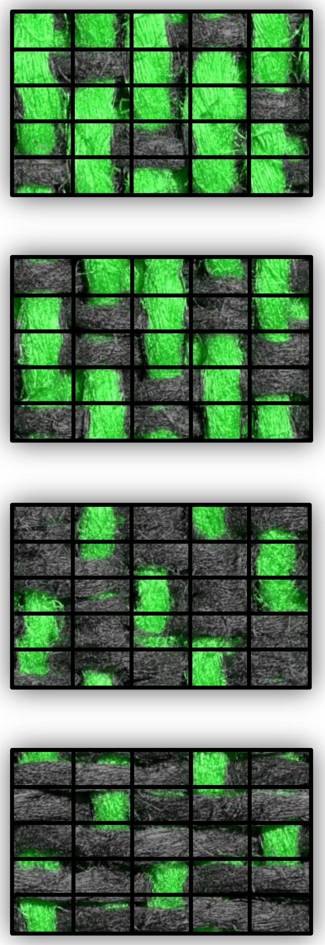
Pixel value = weighted sum of path contributions



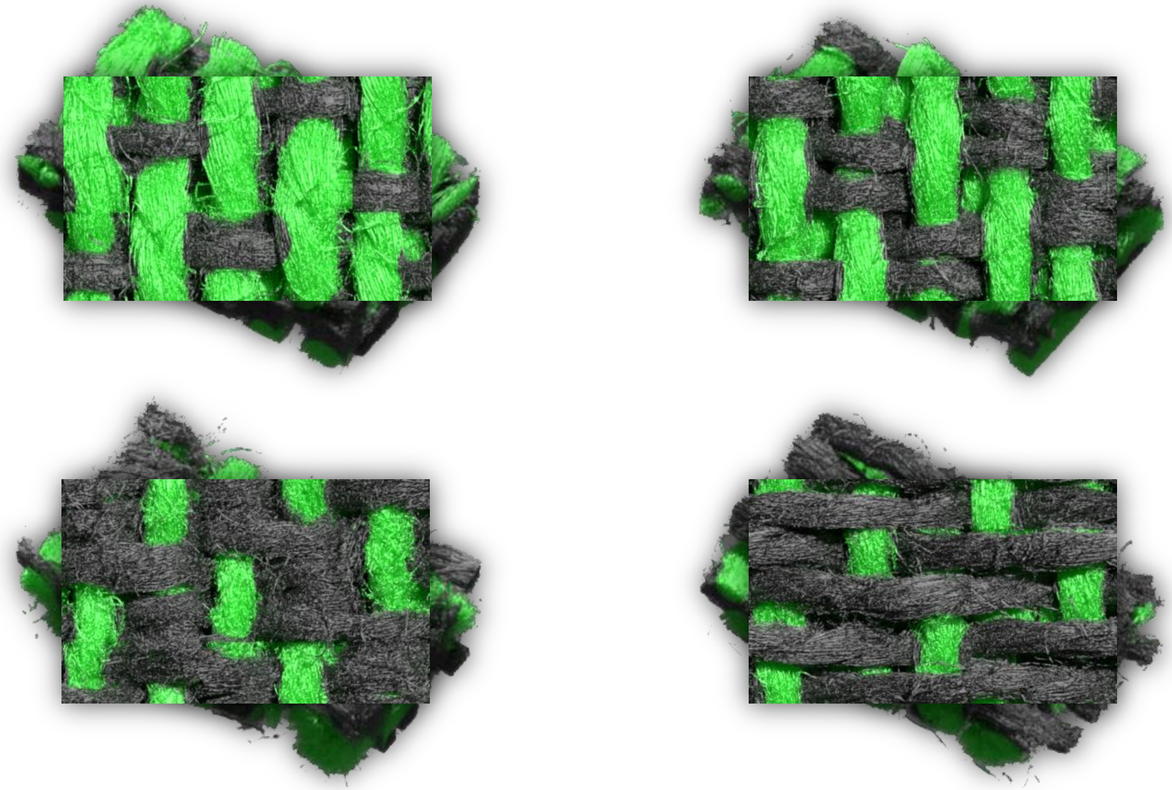
[Veach 1997; Pauly et al. 2000]

Volumetric Model Creation

Exemplar Blocks



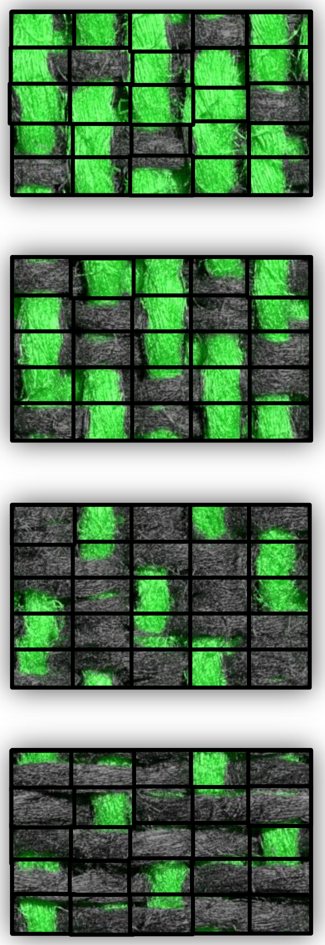
Volumetric Fabric Models
(top view)



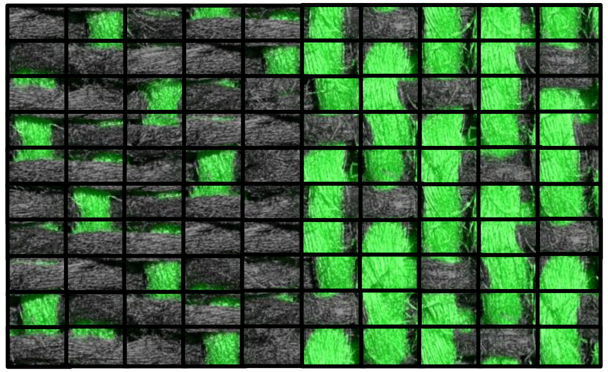
[Zhao et al. 2012]

Volumetric Model Creation

Exemplar Blocks



Final Volume

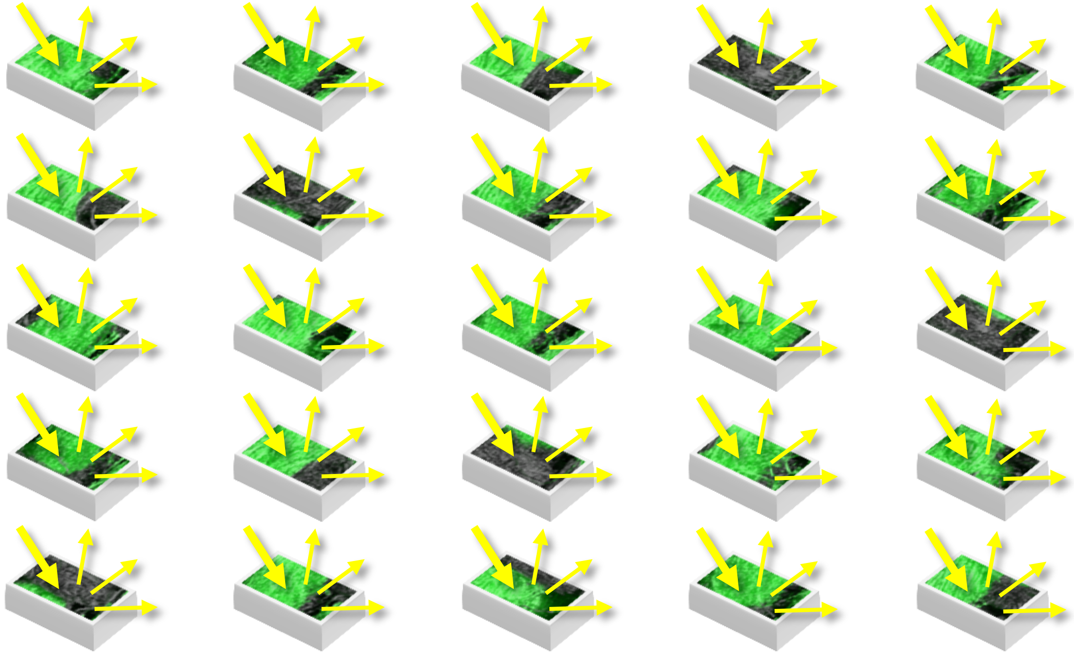


[Zhao et al. 2012]

Key Idea

Idea: Modular Transfer

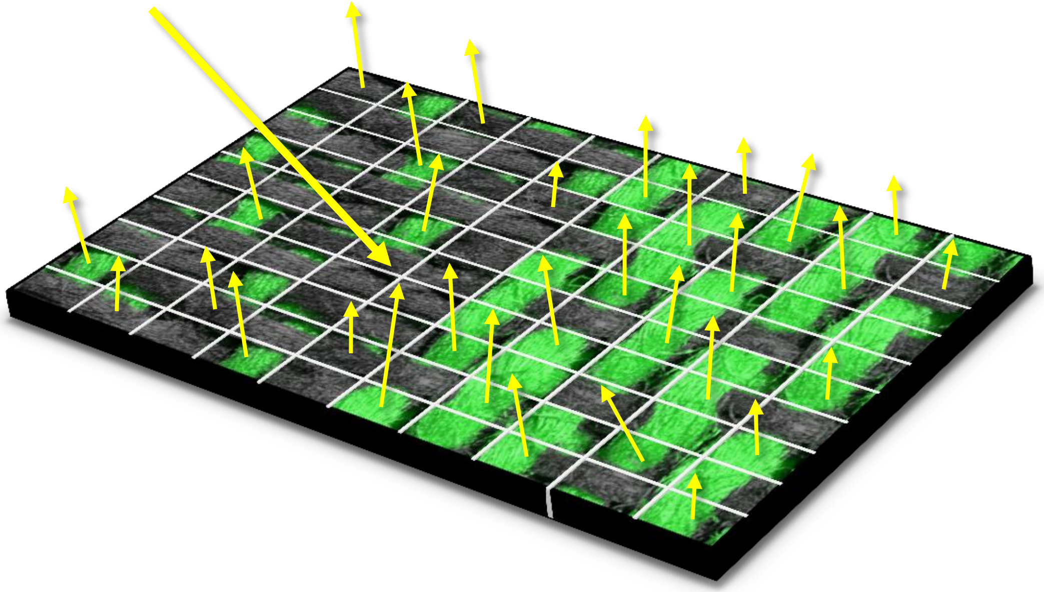
Exemplar Blocks



... ...

Precompute light transport

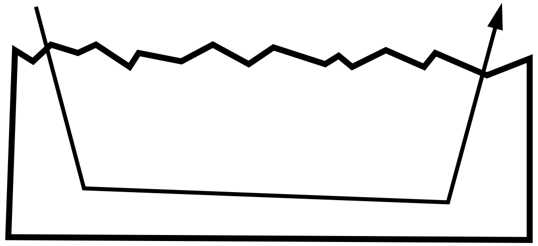
Final Volume



Modularly combine on-the-fly

Solution

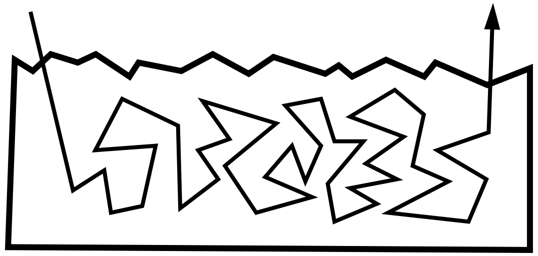
Short light paths



(Easy to compute)

Compute exactly
(brute-force)

Long light paths



(Expensive to simulate)

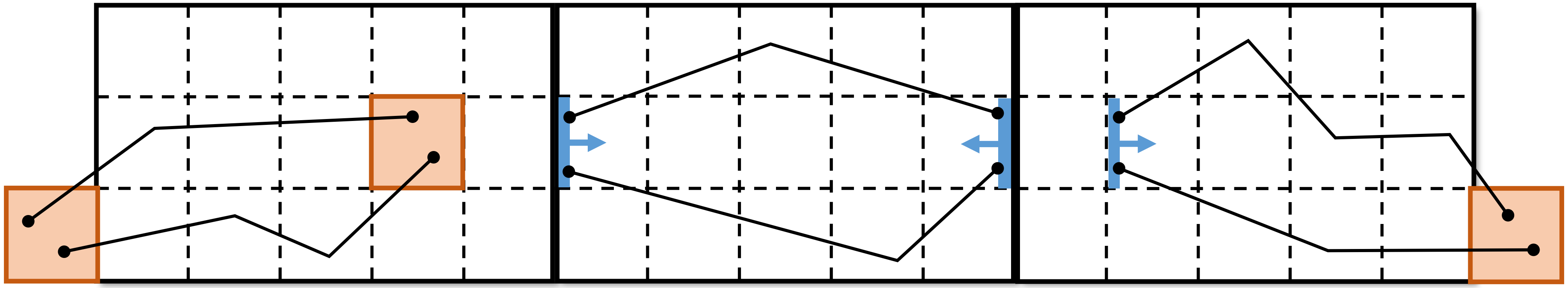
Compute approximately by splitting into **precomputed** and **run-time** components

Definitions

Terminology

- Blocks : Divided volume of equal sizes. Some small number of unique blocks are called exemplar blocks as a representative.
- Voxels : Divided block which provides the resolution.
- Interface : Shared boundary between two neighboring blocks.
- Patches : Oriented faces of voxels on an interface.

3 types of light transfer



Voxel-to-voxel transfer

Patch-to-patch transfer

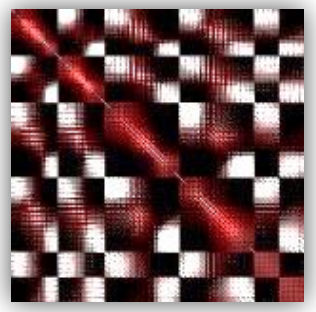
Patch-to-voxel transfer

Note : Voxel-to-patch transfer is just a transpose of Patch-to-voxel transfer

Pipeline

Pipeline Overview

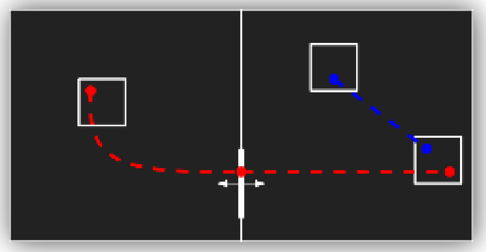
Precomp.



Transfer Matrix Computation

Run-time evaluation

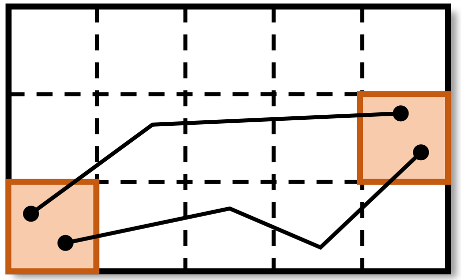
Source Flux Evaluation



Modular Transfer

Final Gathering

Precomputation

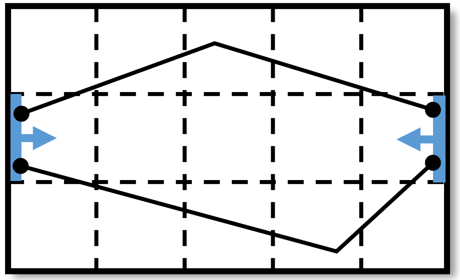


Voxel-to-voxel

Total number of voxels

An $n \times n$ *symmetric* matrix

$$T^{vv}$$

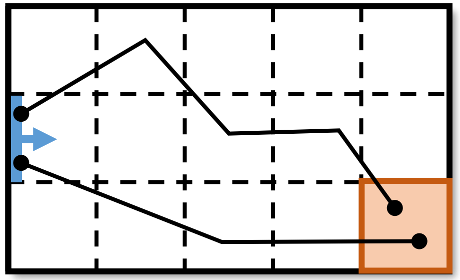


Patch-to-patch

Total number of patches

An $m \times m$ *symmetric* matrix

$$T^{pp}$$

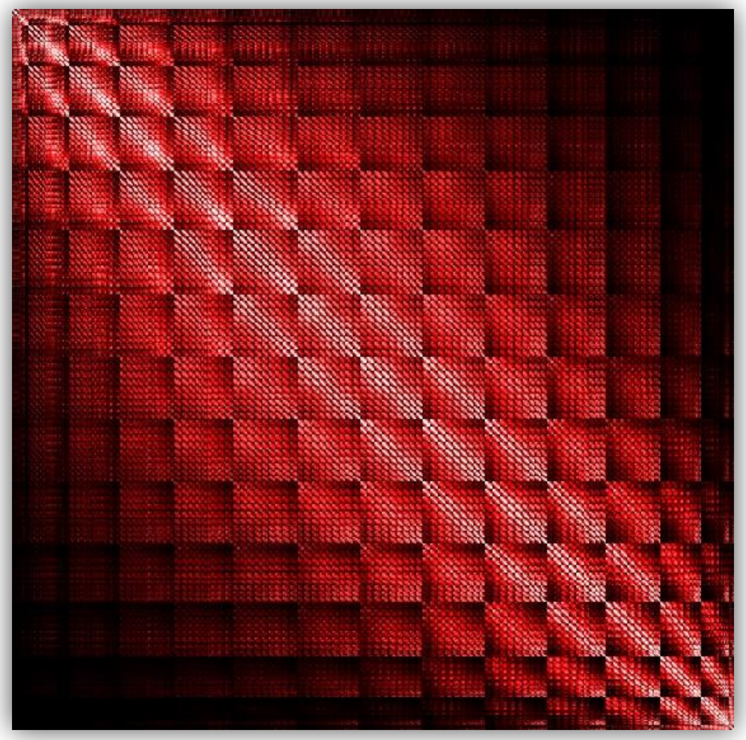


Patch-to-voxel

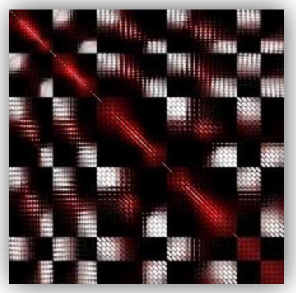
An $n \times m$ *asymmetric* matrix

$$T^{pv} = (T^{vp})^\top$$

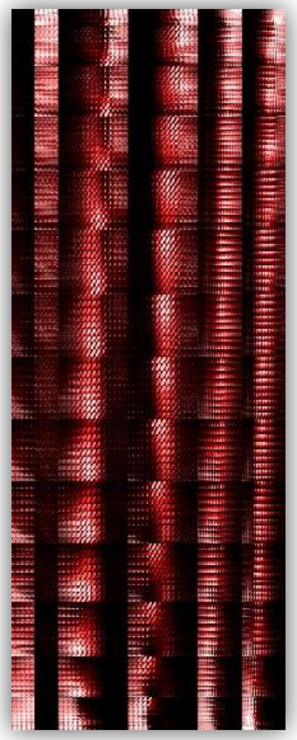
Precomputation



Voxel-to-voxel transfer



Patch-to-patch transfer

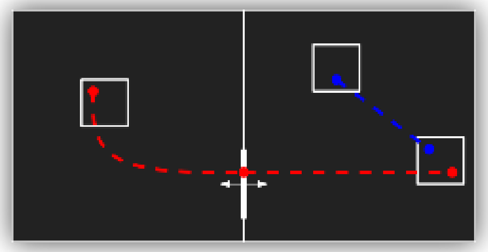


Patch-to-voxel transfer

Run-Time Evaluation

Run-time evaluation

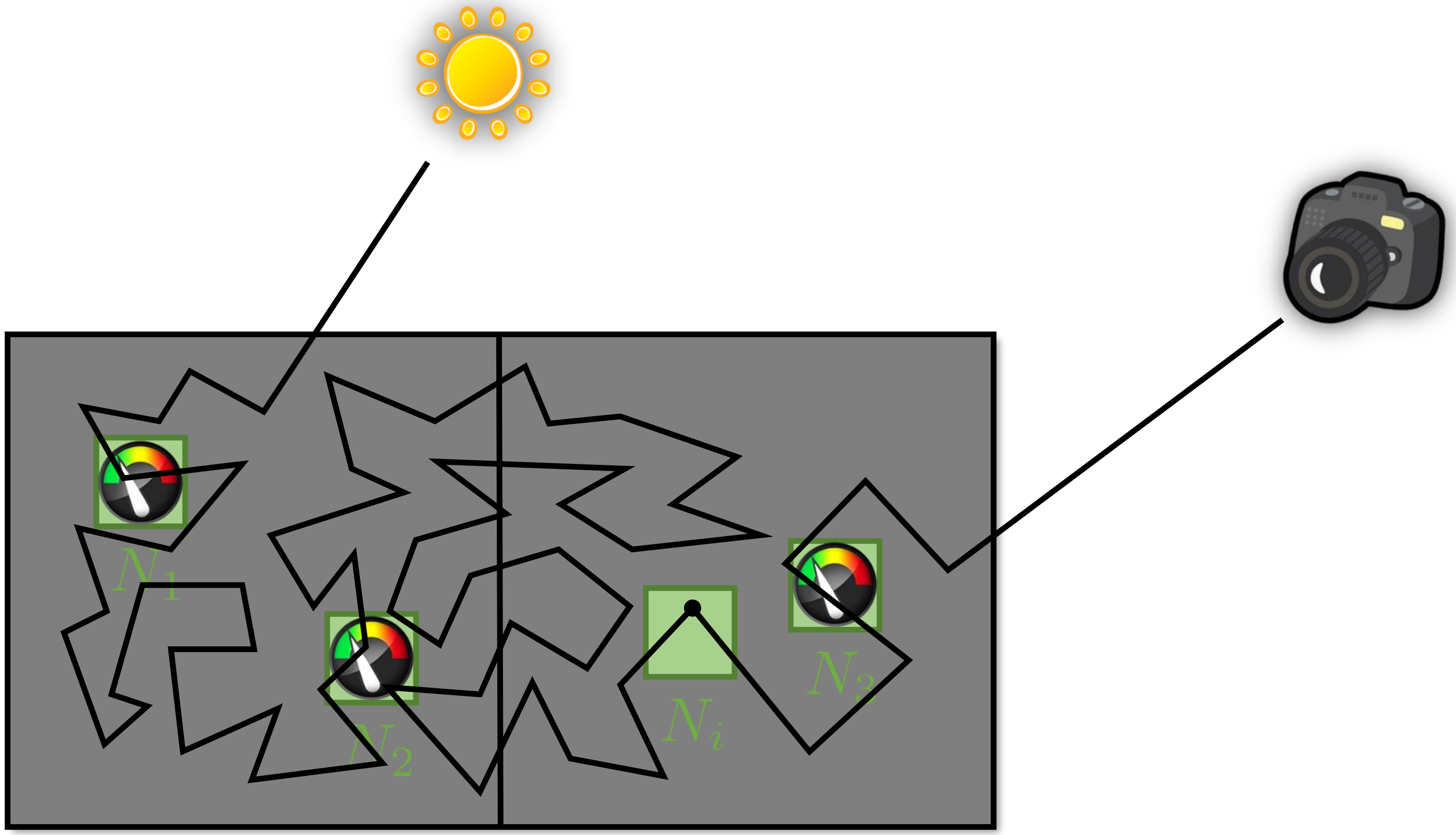
Source Flux Evaluation



Modular Transfer

Final Gathering

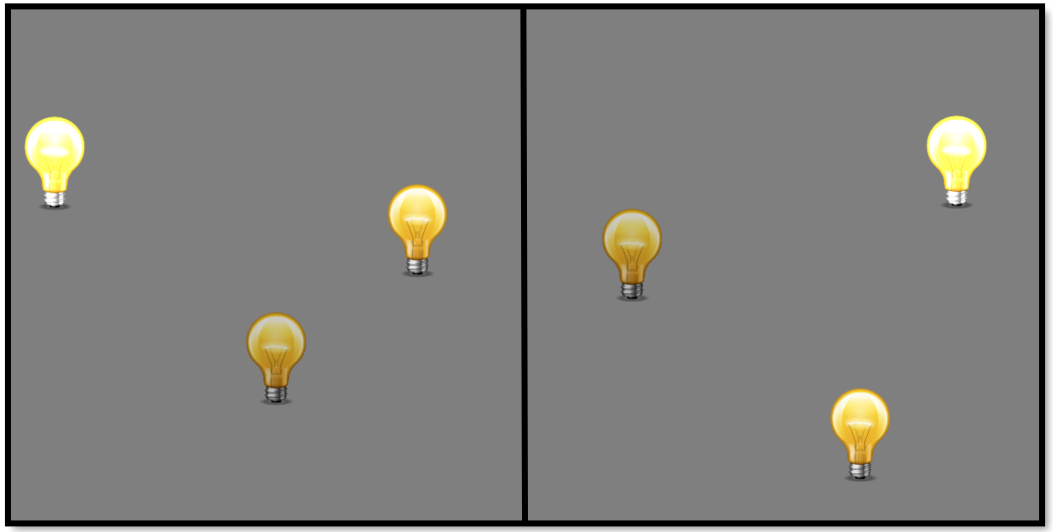
Multiple-Scattered Flux (Φ^m)



Φ^m = (...)

Source Flux (Φ^s) Evaluation

Single-scattered flux



Modular Flux Transfer

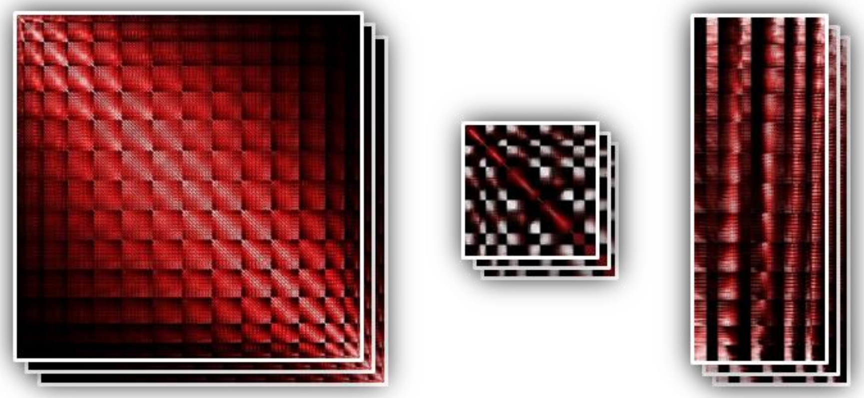
Source Flux

$\boldsymbol{\Phi}^s$ = ( ...)

Multiple-Scattered Flux

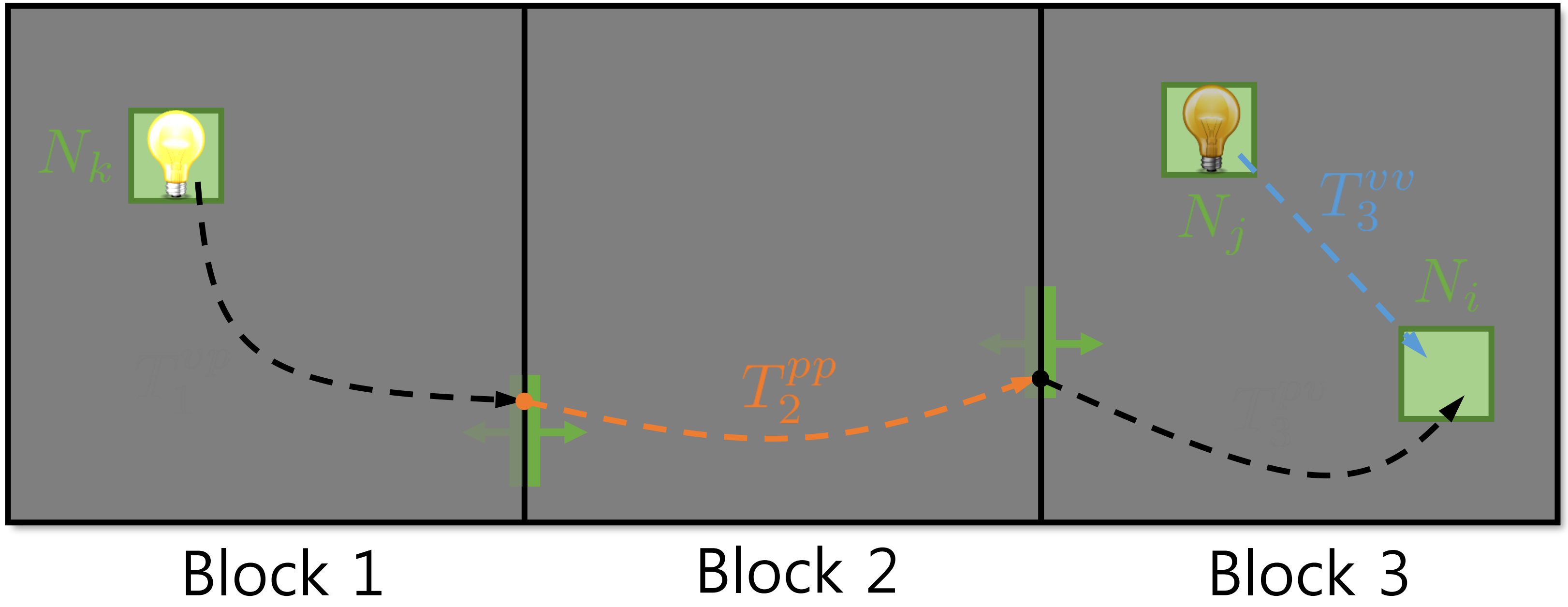
$\boldsymbol{\Phi}^m$ = ( ...)

using



Modular Flux Transfer

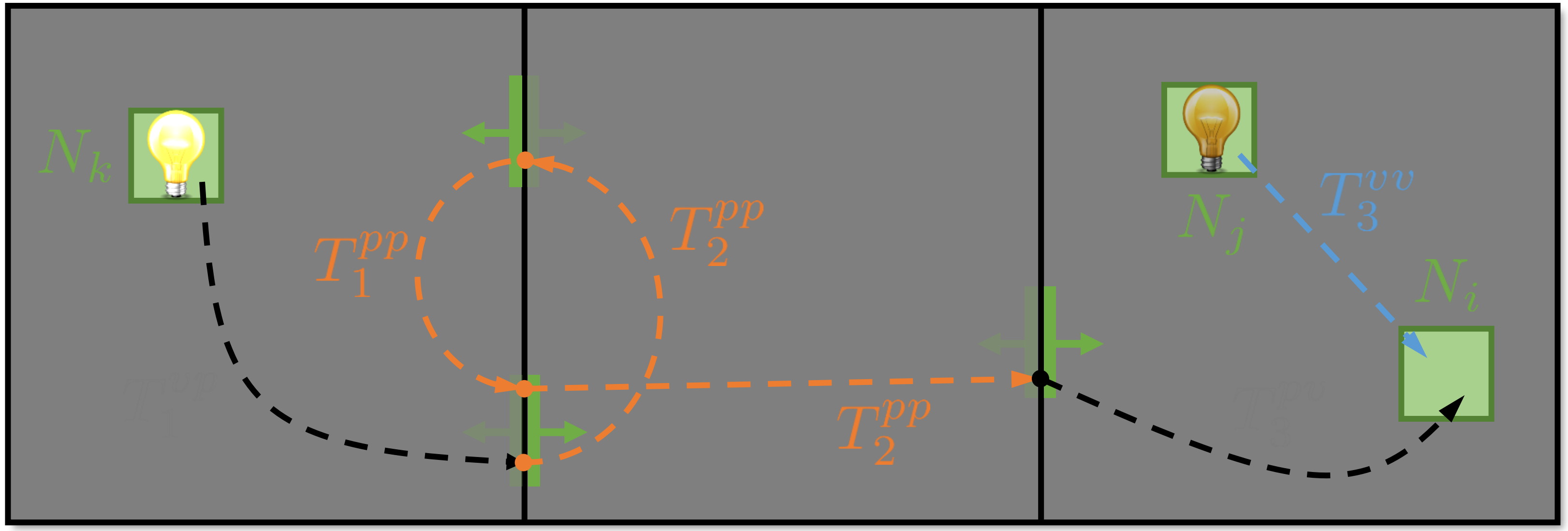
One patch-to-patch transfer



$\boldsymbol{\Phi}^m$ = Intra-block transfer + Inter-block transfer

Modular Flux Transfer

Three patch-to-patch transfers



Block 1 Block 2 Block 3

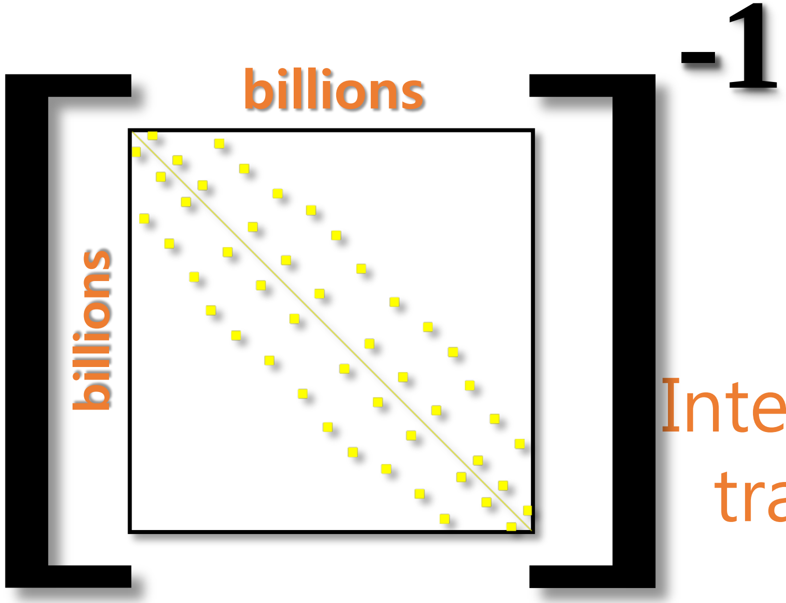
Φ^m = Intra-block transfer + Inter-block transfer

Modular Flux Transfer

$$= \sum_{i=0}^{\infty}$$ Energy propagated with i patch-to-patch transfers

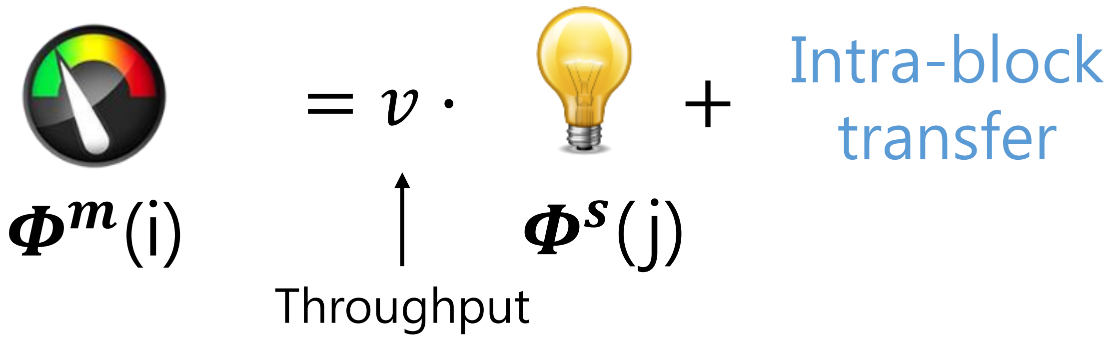
Formulated as a **Neumann series**

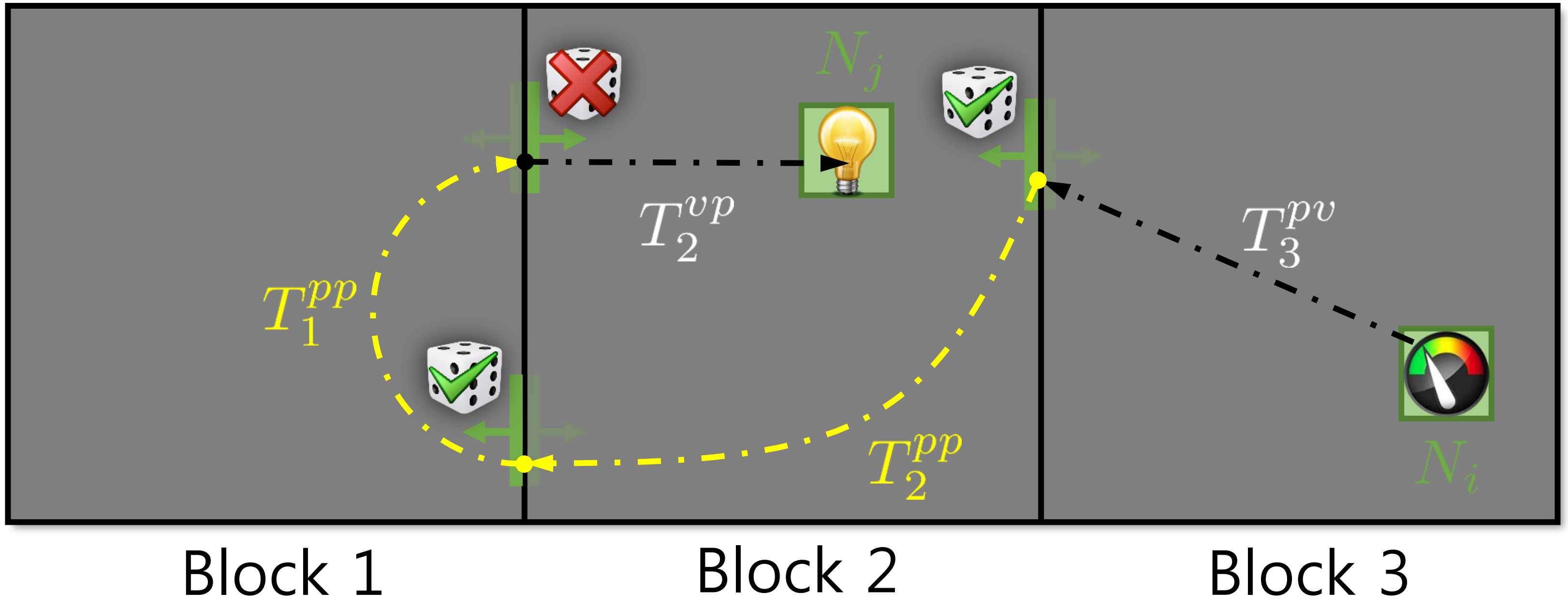
Computed as a **matrix inversion**



Inter-block transfer

Monte Carlo Matrix Inversion





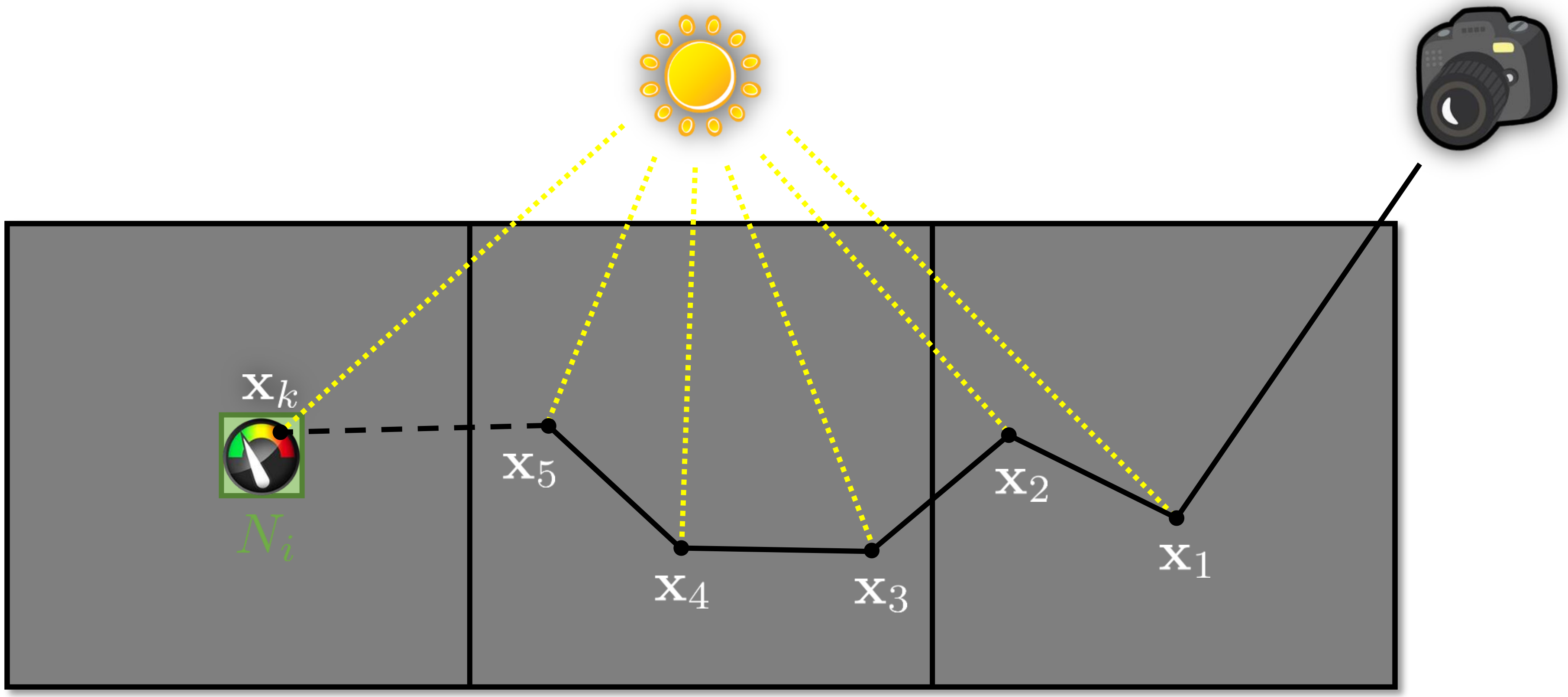
Based on [Forsythe and Leibler 1950]

Final Gathering

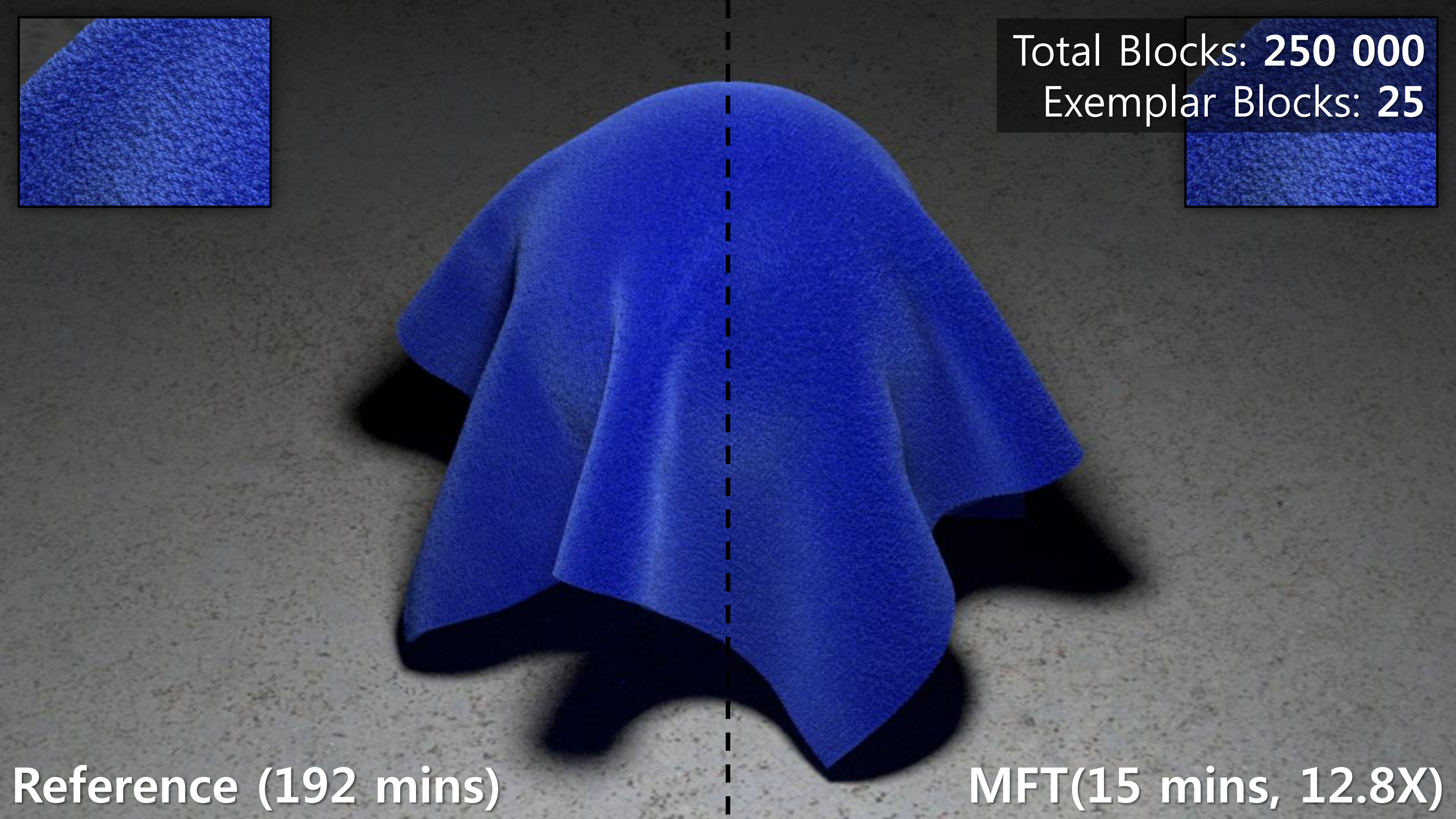
Based on standard volume path tracing

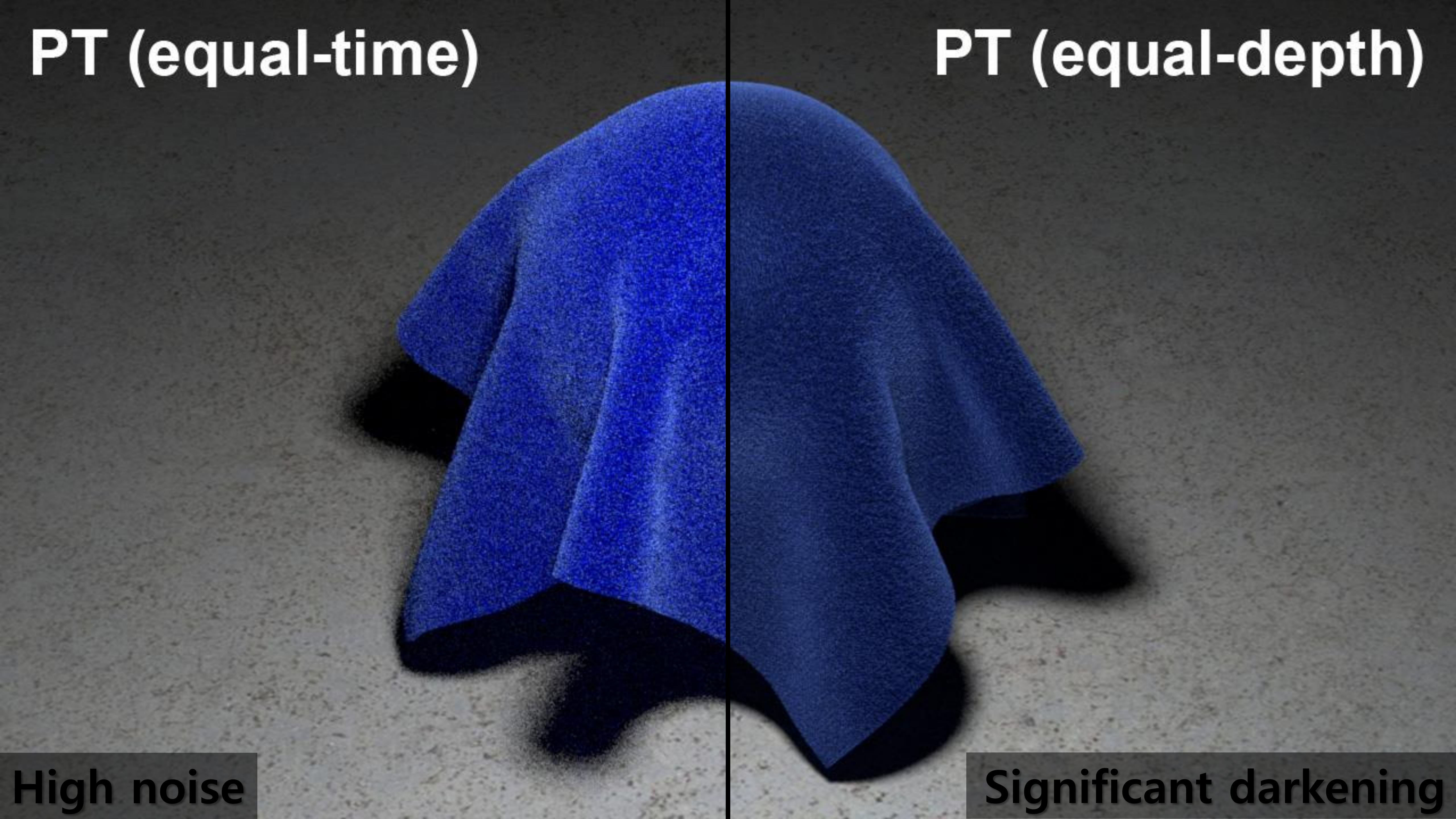
Approximate **indirect illumination** using

Picked k = 6



Results


Total Blocks: 250 000
Exemplar Blocks: 25
Reference (192 mins)
MFT(15 mins, 12.8X)

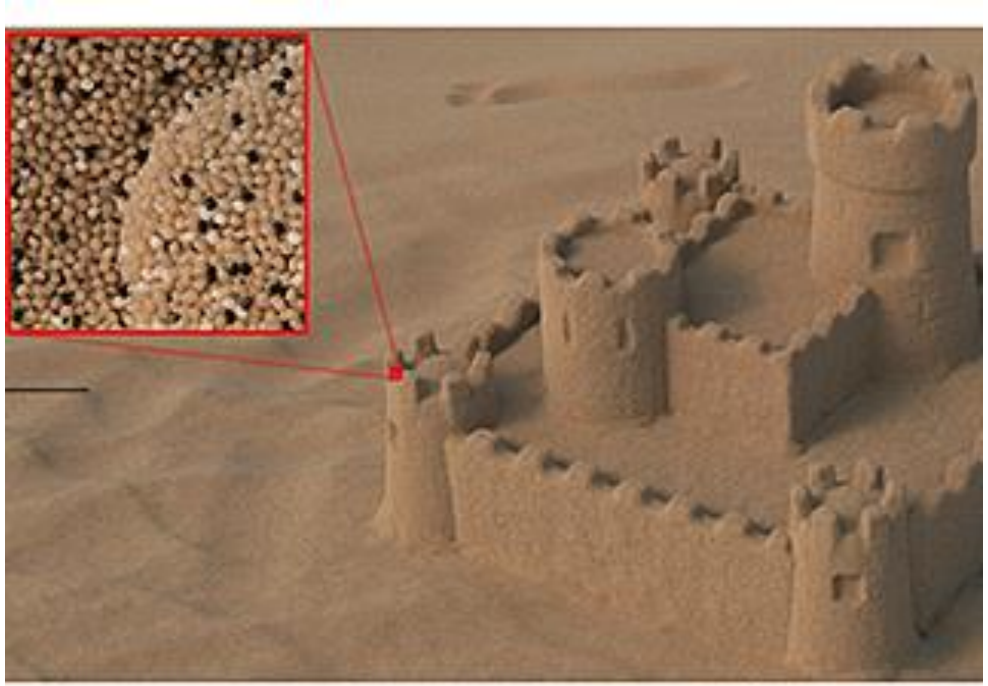

PT (equal-time)
PT (equal-depth)
High noise
Significant darkening

Multi-Scale Modeling and Rendering of Granular Materials

(SIGGRAPH 2015)

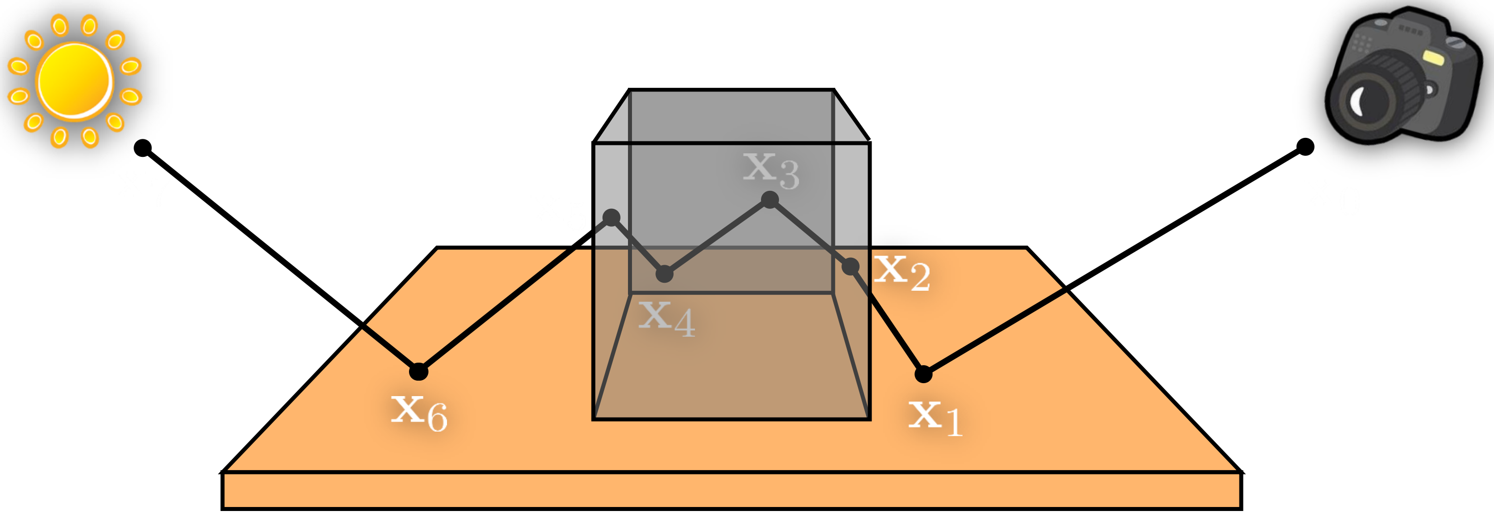
Johannes Meng Marios Papas Ralf Habel
Carsten Dachsbacher Steve Marschner Markus Gross Wojciech Jarosz

Challenge



Background

Explicit Path Tracing (EPT)



To capture the most detailed grain geometry
(expensive)

Volumetric Path Tracing (VPT)

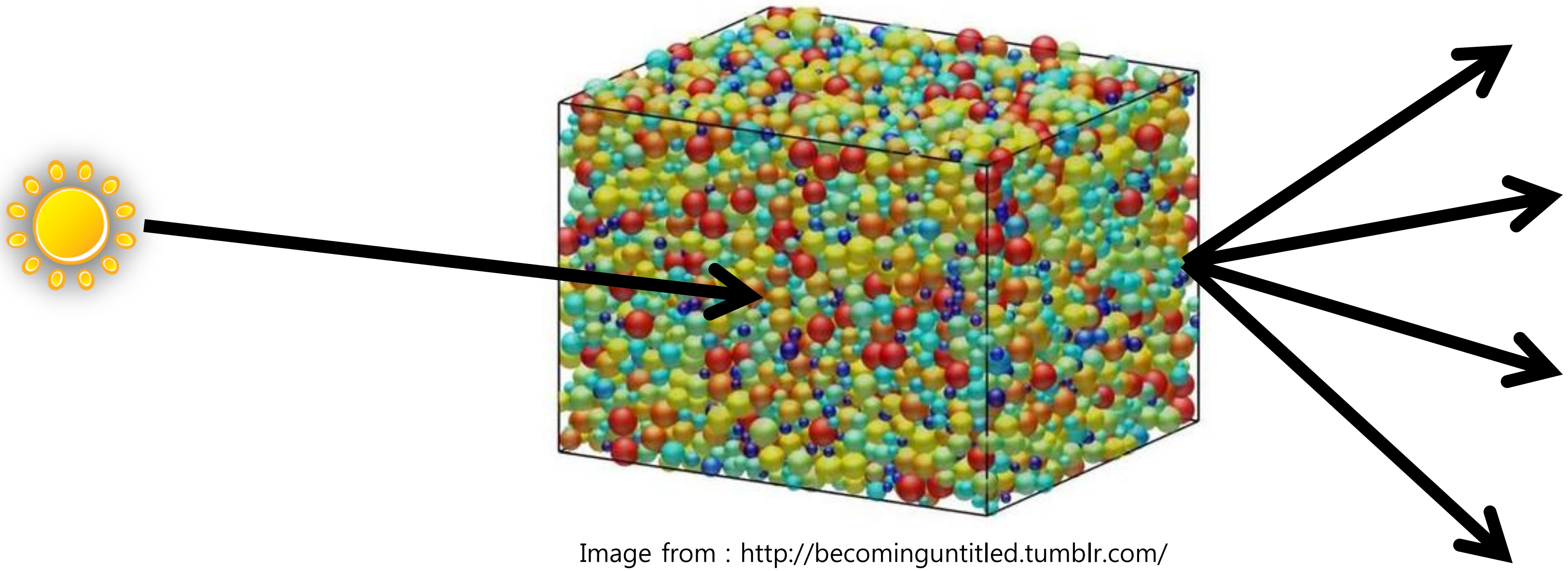
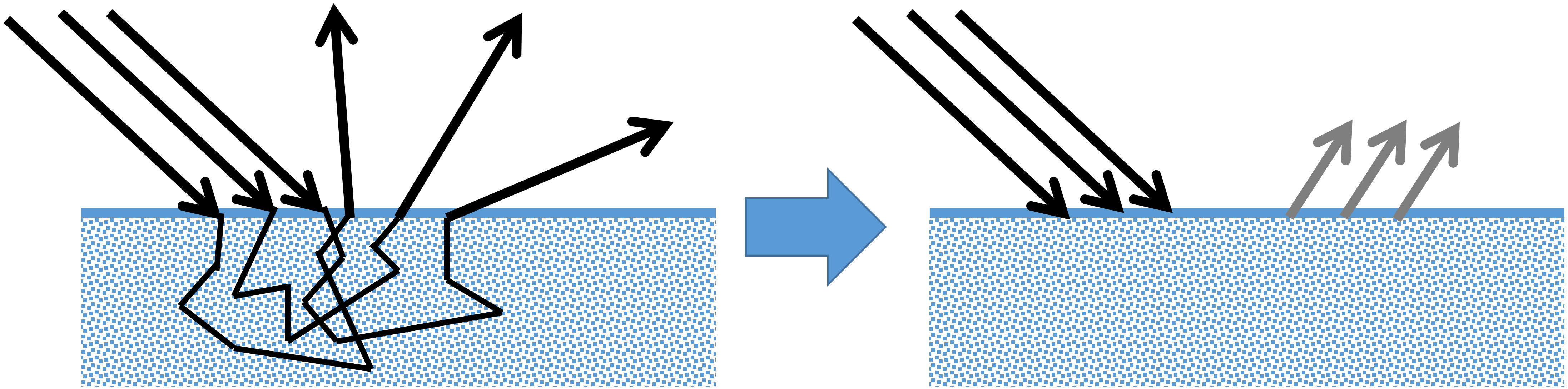


Image from : http://becominguntitled.tumblr.com/

To more efficiently capture larger-scale transport above scale of grains
(less detailed, but efficient)

[Kajiya 1986; Rushmeier 1988]

Diffusion-based approximation (DA)

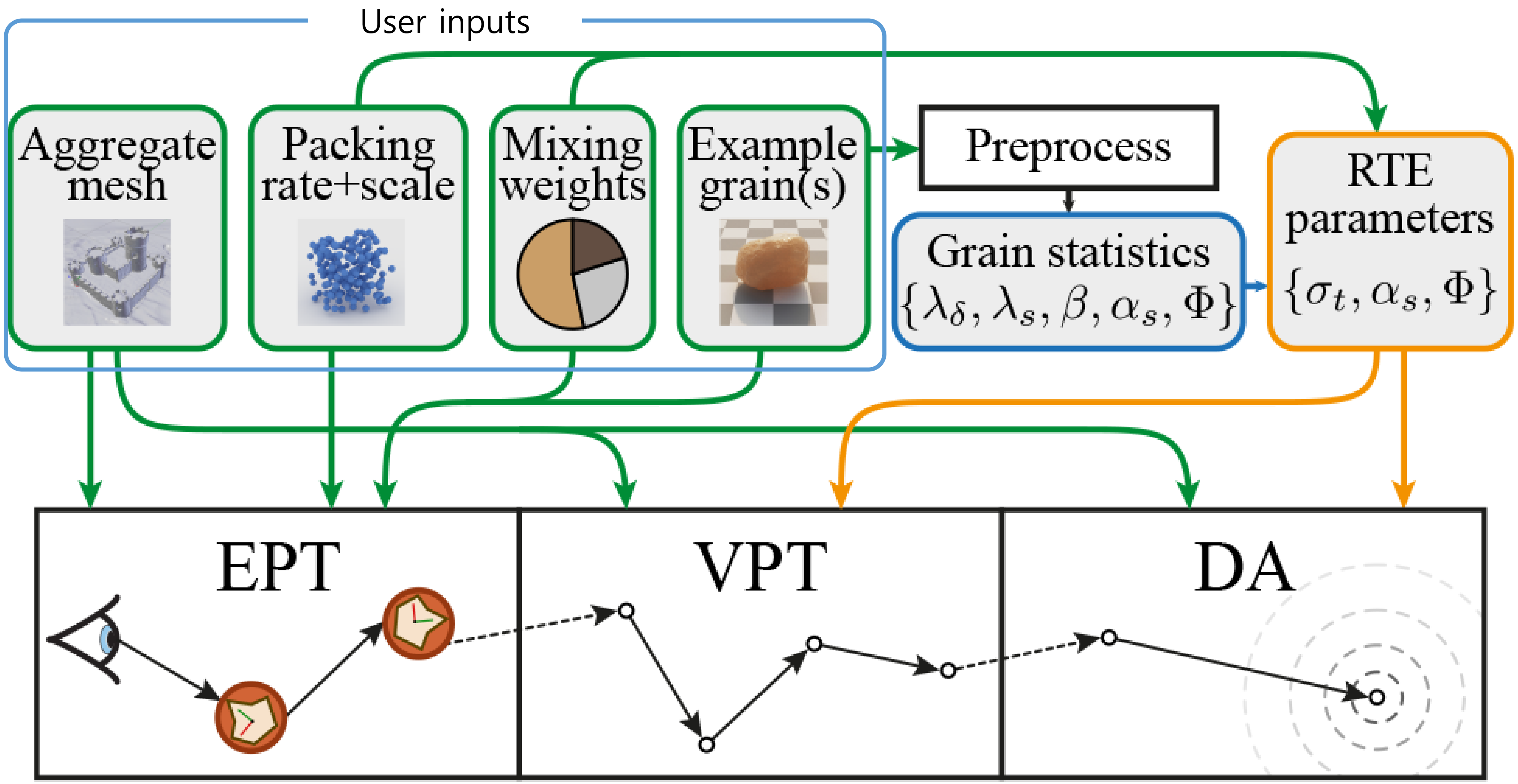


For highly scattering materials at large scale(long paths)
Less expensive than VPT

[Stam 1995; Jensen 2001]

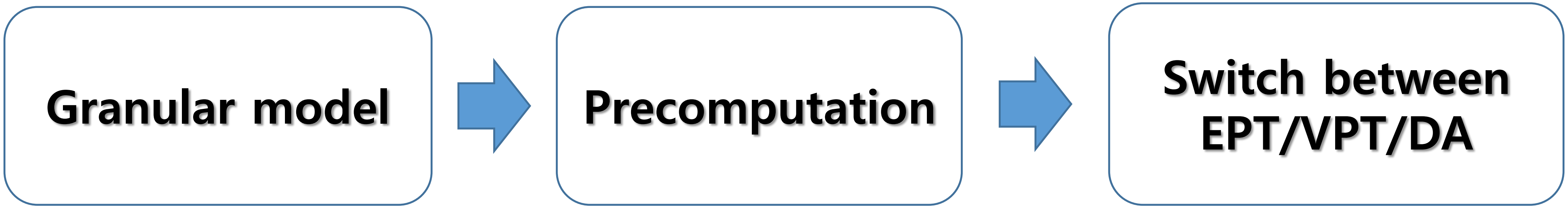
Key Idea

Idea: Mix them!



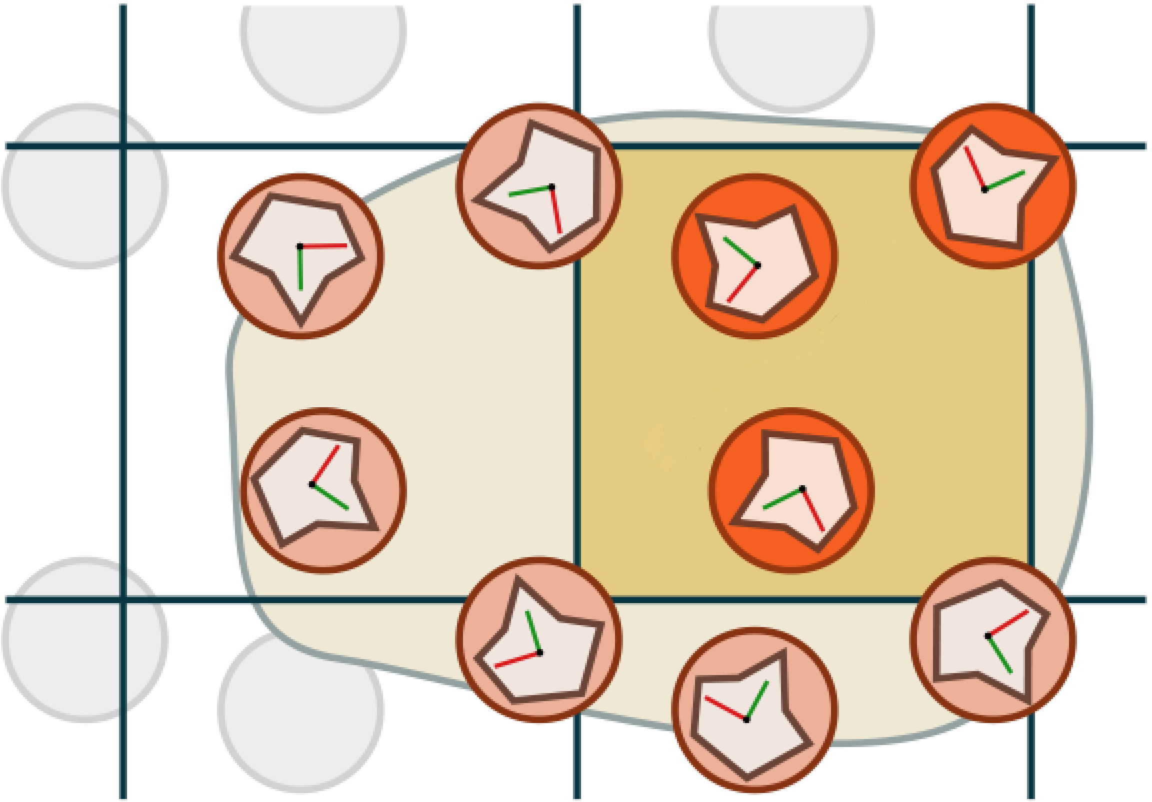
Method

Overall method



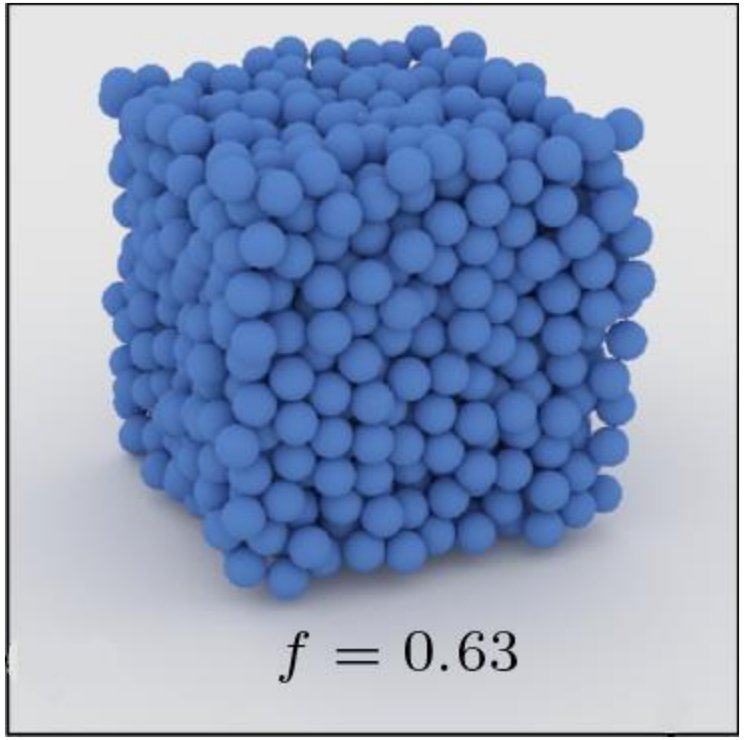
Granular model

Tiled sphere packings



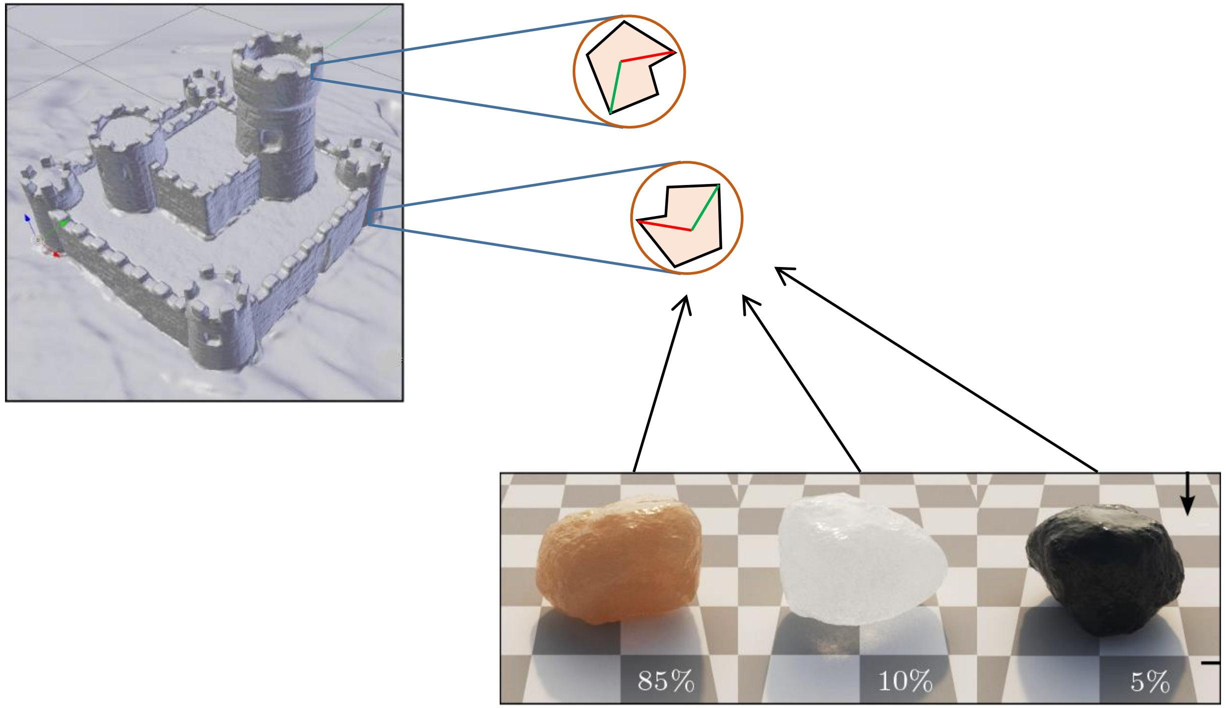
Granular model

Tiled sphere packings



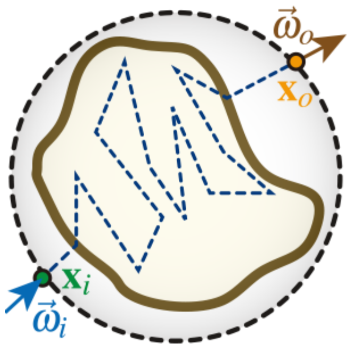
Granular model

Randomized instantiation

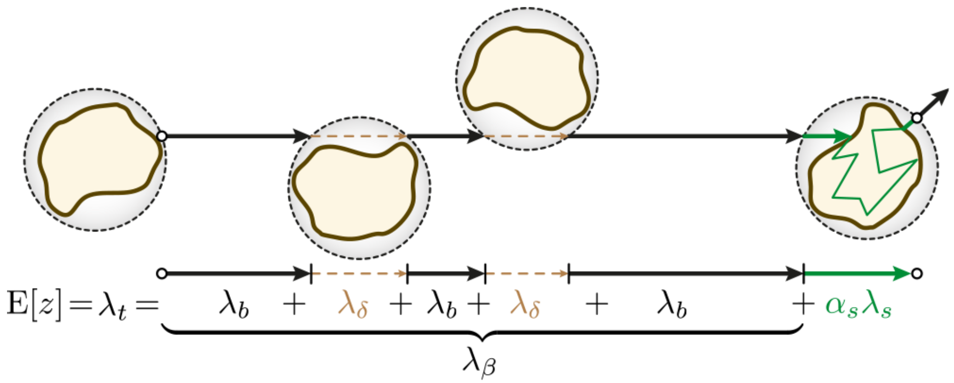


Precomputation for parameters

- Precompute radiative transfer parameters
  - Teleportation Transport Model
    - Inter-grain transport
    - Intra-grain transport



- Classical RTE & Diffusion Parameters
  - The phase function & albedo
  - Combined free-flight distribution
  - Effective RTE and diffusion parameters



Switching between rendering techniques

The actual rendering starts with EPT for grain details

EPT->VPT : $\sigma_k > \tau \frac{N_k}{N}$

k : # bounce
σ_k : standard deviation of N_k vertex positions
τ : user-specified grain radius
N_k : # remaining ray at k
N : # paths per pixel (sample ray)

Switching between rendering techniques

VPT->DA :

min_dist(x_i^k, boundary mash surface) $>$ min($1/\sigma_t'$,$0.5/\sigma_{tr}$)

(when approximations are not too noticeable)

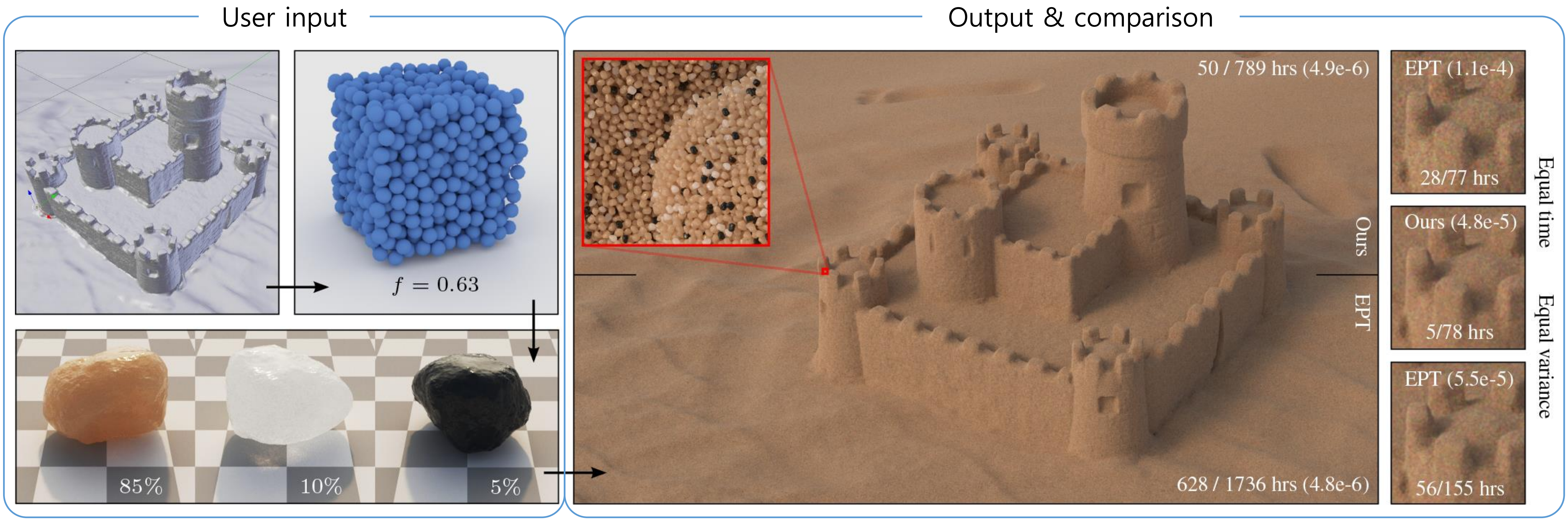
x_i^k : VPT path vertex

$1/\sigma_t'$: reduced mean free path

$0.5/\sigma_{tr}$: half diffuse mean free path

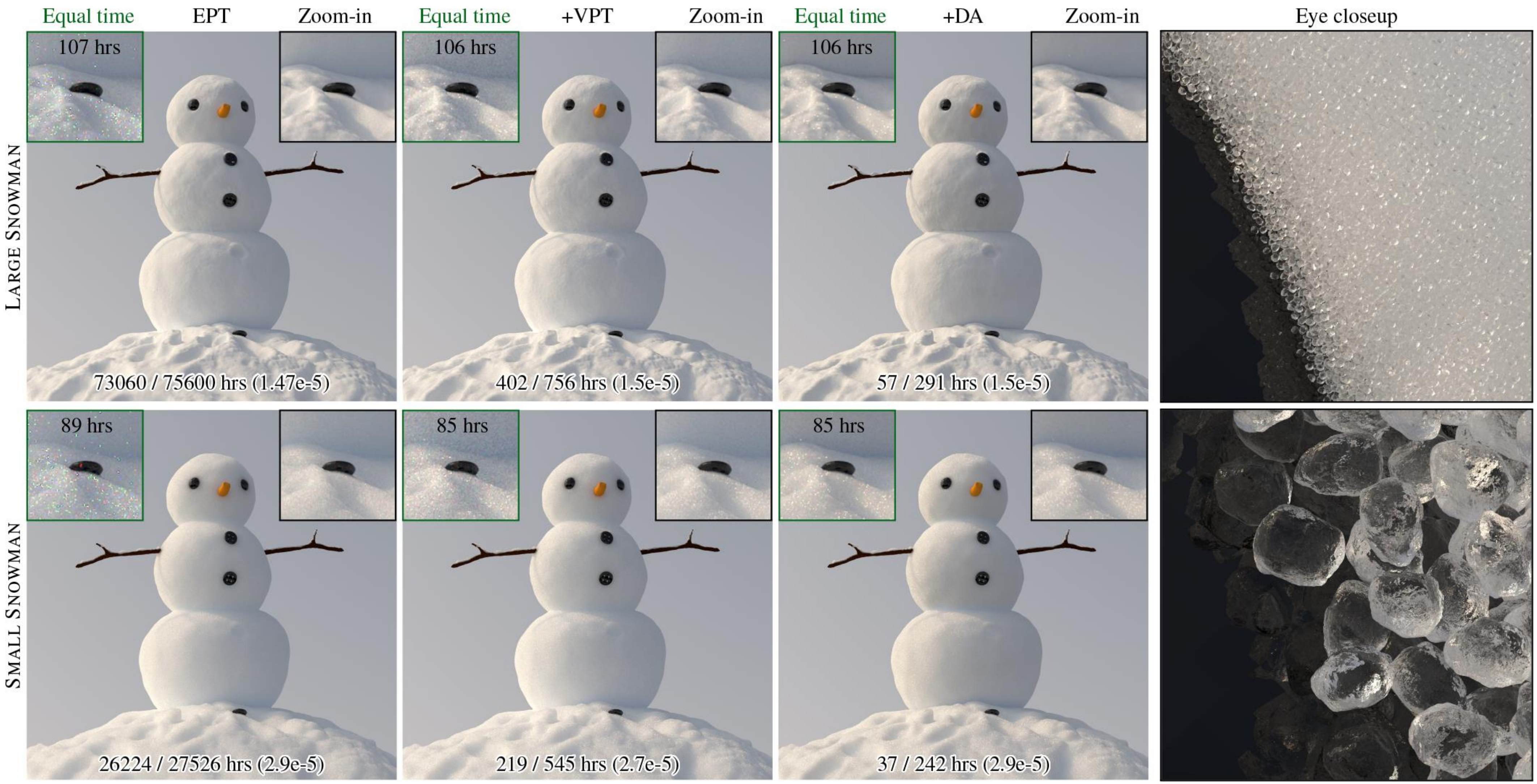
Result

Result



User input
Output & comparison
$f = 0.63$
85%
10%
5%
50 / 789 hrs (4.9e-6)
Ours
EPT
628 / 1736 hrs (4.8e-6)
EPT (1.1e-4)
28/77 hrs
Ours (4.8e-5)
5/78 hrs
EPT (5.5e-5)
56/155 hrs
Equal time
Equal variance

Result


Equal time
EPT
Zoom-in
Equal time
+VPT
Zoom-in
Equal time
+DA
Zoom-in
Eye closeup
LARGE SNOWMAN
107 hrs
73060 / 75600 hrs (1.47e-5)
106 hrs
402 / 756 hrs (1.5e-5)
106 hrs
57 / 291 hrs (1.5e-5)
SMALL SNOWMAN
89 hrs
26224 / 27526 hrs (2.9e-5)
85 hrs
219 / 545 hrs (2.7e-5)
85 hrs
37 / 242 hrs (2.9e-5)

Thank you!
Questions?

Quiz

- 1. What kind of transfer is used to perform inter-block transform?
  - 1. voxel-to-voxel transfer
  - 2. voxel-to-patch transfer
  - 3. patch-to-patch transfer

- 2. What is the most detailed method in rendering granules?
  - 1. EPT (Explicit Path Tracing)
  - 2. VPT (Volumetric Path Tracing)
  - 3. DA (Diffusion-based Approximation)